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ABSTRACT

Presented are a variety of surface run-off experiments for high school students. The experiments are analogies to basic concepts about water intake, as related to water delivery, soil properties and management, floods, and conservation measures. The materials needed to perform the experiments are easily obtainable. The experiments are followed by a general discussion on the hydrologic cycle, the causes of floods and types of floods. The publication concludes with the role of research in studying water intake by soil. (BB)

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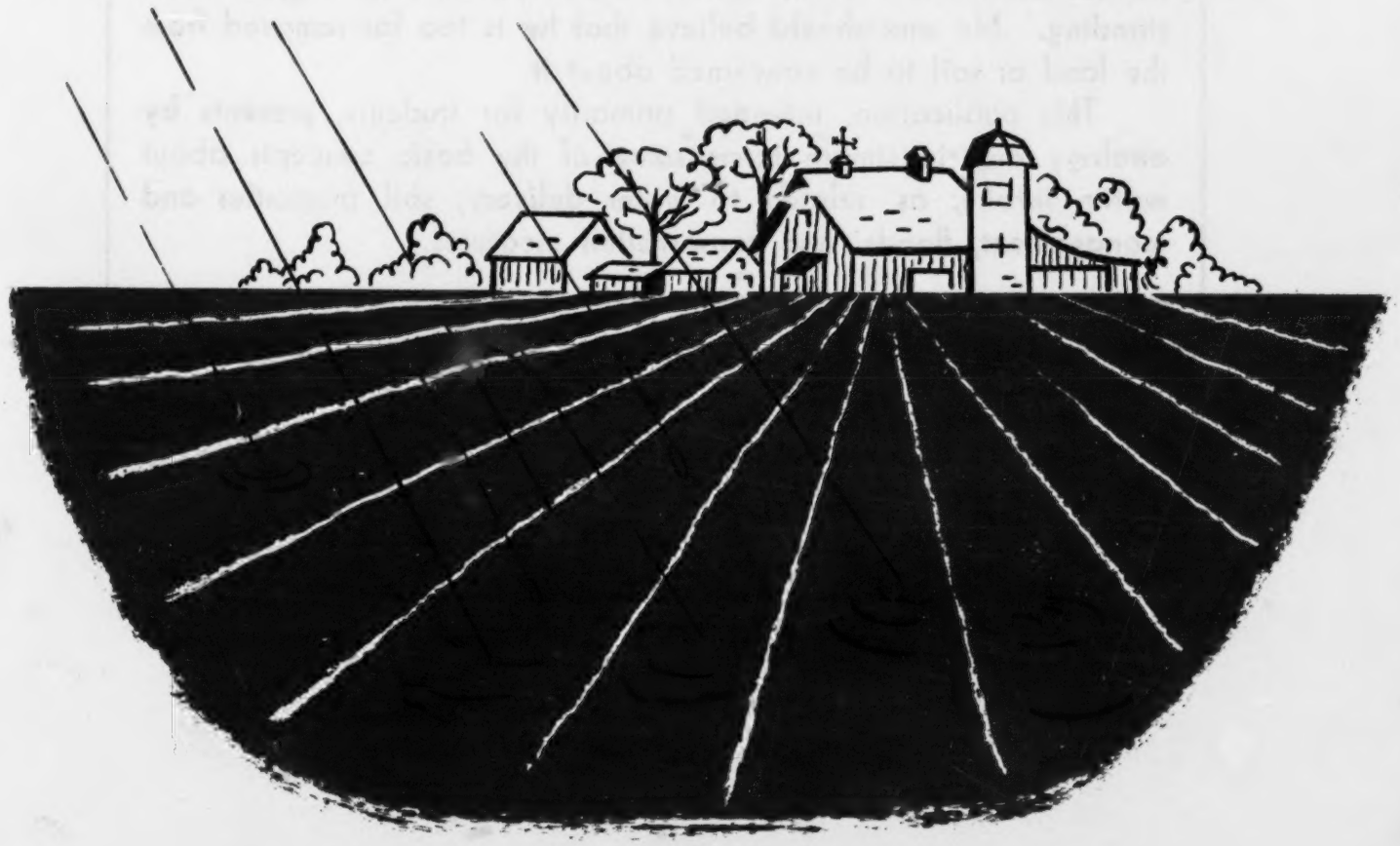
WATER INTAKE BY SOIL

EXPERIMENTS FOR HIGH SCHOOL STUDENTS



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Water problems are rapidly becoming a major concern for everyone.

It's easy to see why this is true. Our population is growing steadily year by year. The more people there are, the more water we use—not only for personal uses, but also for manufacturing and for growing our food and fiber.

Ironically, some parts of our country may be struggling with the problem of too much water—floods and erosion—when at the same time other areas face the problem of water scarcity. Regardless of what the problem is, we must realize that the *soil*, onto which Nature delivers the water, deserves much of our attention and understanding. No one should believe that he is too far removed from the land or soil to be concerned about it.

This publication, intended primarily for students, presents by analogy and in simple terms some of the basic concepts about *water intake*, as related to water delivery, soil properties and management, floods, and conservation measures.

Washington, D.C. August 1963

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WATER INTAKE BY SOIL

EXPERIMENTS FOR HIGH SCHOOL STUDENTS

By LLOYD L. HARROLD,[1] *Soil and Water Conservation Research Division, Agricultural Research Service*

The next time you see it raining hard, watch how falling raindrops splash soil on basement windows, on the sides of houses, and on the leaves of plants and vegetables.

As more and more raindrops fall, some of the water begins to run off the soil. Little trickles become big trickles. Notice how much of this rain soaks into the soil . . . and how much of it runs off into gutters, creeks, and rivers.

If you observe runoff water closely, you may notice that two factors determine how fast it runs—the slope of the land and the presence or absence of soil cover such as grass, leaves, or mulches. Some runoff water may be clear, but more often it may be muddy or silt laden. Why is it muddy?

Do you suppose more of the rainfall could have been absorbed by the soil? It all depends on how well the soil is managed. The principles of soil management and water conservation are not hard to understand. The first step is to learn about the soil sponge.

SOIL SPONGE

Remember we said that slope and cover determine how fast water runs off—or in other words, how much of it is absorbed by the soil and how much escapes. You can perform an interesting experiment to demonstrate exactly what happens to soil and water when a rainstorm comes. To do this, you will need the following items:

- A plastic sponge, moistened.
- Sheets of blotter paper, moistened.
- A plastic squeeze bottle—like those used for dampening laundry.
- A supply of water.

The sponge represents soil in excellent condition for water intake. It is porous, and, like porous soil, absorbs water rapidly and provides good drainage. Large pores allow air to get into the sponge. Small pores hold water against the pull of gravity. This is called capillary water. Most of this capillary water in the soil is available for farm crops, lawns, shrubs, flowers, trees—growing plants.

The blotter paper represents a heavy, tight soil in poor condition for water intake. Its pores are small and they absorb water very slowly. Drainage is extremely slow. Very little air gets into the pores. Just as the small pores in the blotter hold much water, so do the pores in a heavy, tight soil hold a fairly large amount. But all this water is not available for crops because much of it is held too tightly. A clayey, poorly aggregated soil, like the blotter paper, stays wet for long periods.

The plastic squeeze bottle provides a means of applying water to the sponge and blotter paper. If such a bottle is not available, substitute a 1-quart paper milk container. Using a large needle or a nail, punch holes in a round area (about an inch in diameter) on one side near the top of the container. Close the cover tightly. By inverting the container, or plastic bottle, and squeezing it, you can "make it rain" for this test.

Now you are ready to observe some of the problems of water intake by soils.

Test No. 1: Sponge Alone

Hold the sponge in one hand and the squeeze bottle full of water in the other. Slope the broad side of the sponge so you can see the water run off.

Tilt the bottle and squeeze it. Watch the water fall onto the sponge (fig. 1). See how fast the sponge absorbs the water. Can you apply water from the bottle fast enough to cause runoff? Did you ever see it rain this hard?

Continue applying water until some begins to drop from the bottom of the sponge.

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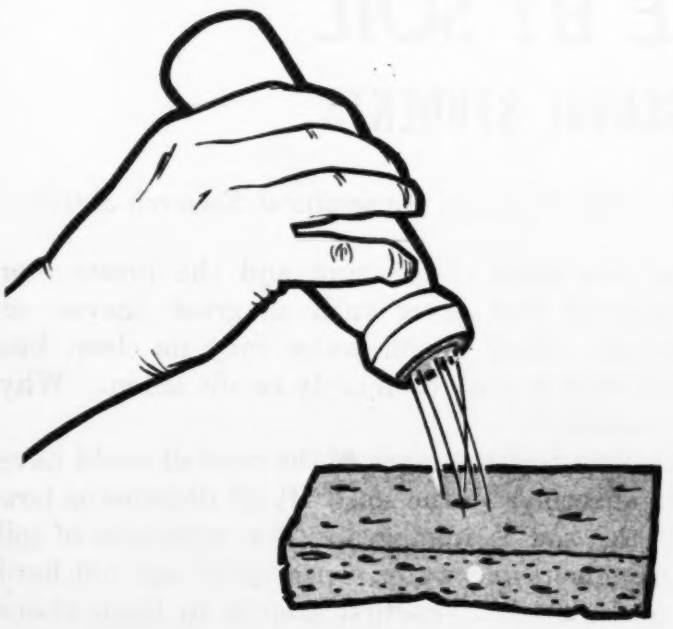

Figure 1.—Water being applied from a squeeze bottle to a plastic sponge. This demonstrates what happens when rain falls on porous soil. There is no runoff.

Now let's review what you have demonstrated. Keep in mind that the sponge represents a porous soil. And its surface is not disturbed by the beating and packing action of raindrop energy. A complete vegetative cover of trees or grass or a mulch cover provides such protection to soils on farm fields, city gardens, or lawns.

You applied water very fast. This could have been a heavy summer thundershower. The soil could have been quite dry before the rain. Perhaps vegetation needed water. In this condition, there was enough pore space in a foot depth of this soil to absorb 3 inches of rain before the soil became saturated. Like most summer storms of short duration, the water you applied was also brief. How good it was that all of the rain went into the soil! There was no runoff and no erosion. Water absorbed by the soil was enough to meet vegetation needs for several days, at least.

Now squeeze the water out of the sponge, and the rainstorm test can be repeated. That is the way it works in nature. Vegetation and evaporation take water out of the soil pores. As the soil gets drier and drier, a greater and greater reservoir for water absorption develops in the soil.

You can see how this works by filling a drinking glass with small marbles and adding water until its surface is level with the top of the marbles. This represents a saturated soil. Then pour out about half the water. Note that some pore space between the marbles has no water, but the marbles above the water are still wet. This is like water draining from the soil after a heavy rain. The marbles will dry after a while. The water has been evaporated. In the field, vegetation removes some of this water too.

Now, fill the glass again with water. This is like rain from the next storm refilling some of the soil pores with water. Thus, the wetting and drying of the soil goes on continuously. The hotter the temperature and the more completely vegetation covers the soil—the faster the soil dries out. It could also be said that this is how soil is quickly made ready to absorb more rainfall. In the winter the drying rate is low. Soils remain

Figure 2.—Water being applied to a blotter placed over the sponge. This demonstrates what happens when rain falls on a crusted soil surface over a porous topsoil. The sponge absorbs very little water; runoff is heavy.

wet for longer periods. The soil reservoir for water absorption develops very slowly then.

Test No. 2: Blotter Paper on Top of Sponge

In the next test, place the moist blotter paper on top of the sponge. (Squeeze the excess water from the sponge before starting this test.) Now apply water from the squeeze bottle and watch how little penetrates the blotter into the sponge. Note how much water runs off (fig. 2).

Let's consider what this test represents. This could be a field of grass plowed under, or a garden or lawn spaded, worked down and smoothed by disking, harrowing, hoeing, raking, and the like. These tillage operations broke up the larger soil crumbs into fine particles. These particles filled and clogged the soil pores at the surface. Raindrops puddled and packed the surface. A fine, compact, blotterlike surface developed. When dry, it was a crust. Beneath the crust was an open, loose, and porous soil—just like the sponge. You can see this condition in your garden or in row-crop fields—especially in the growing season when heavy rainstorms are common.

This plowing, fitting, and raindrop puddling is just one way in which the *blotter-sponge* arrangement develops naturally on bare soils. It is quite difficult for the soil to absorb much of the high-intensity summer rainfall when the farm fields, the overgrazed rangeland, the trampled lawns, or bare garden soils are in such poor physical condition.

Results from watershed research studies at Coshocton, Ohio, showed only ½ inch of a 1-inch rainstorm in July was absorbed by a crusted cornland soil. Two tons of soil were washed off each acre of this cornfield. Records showed that the 7-inch plow layer before this storm had a capacity to absorb nearly 3 inches of water. The rainwater in this storm simply could not pas

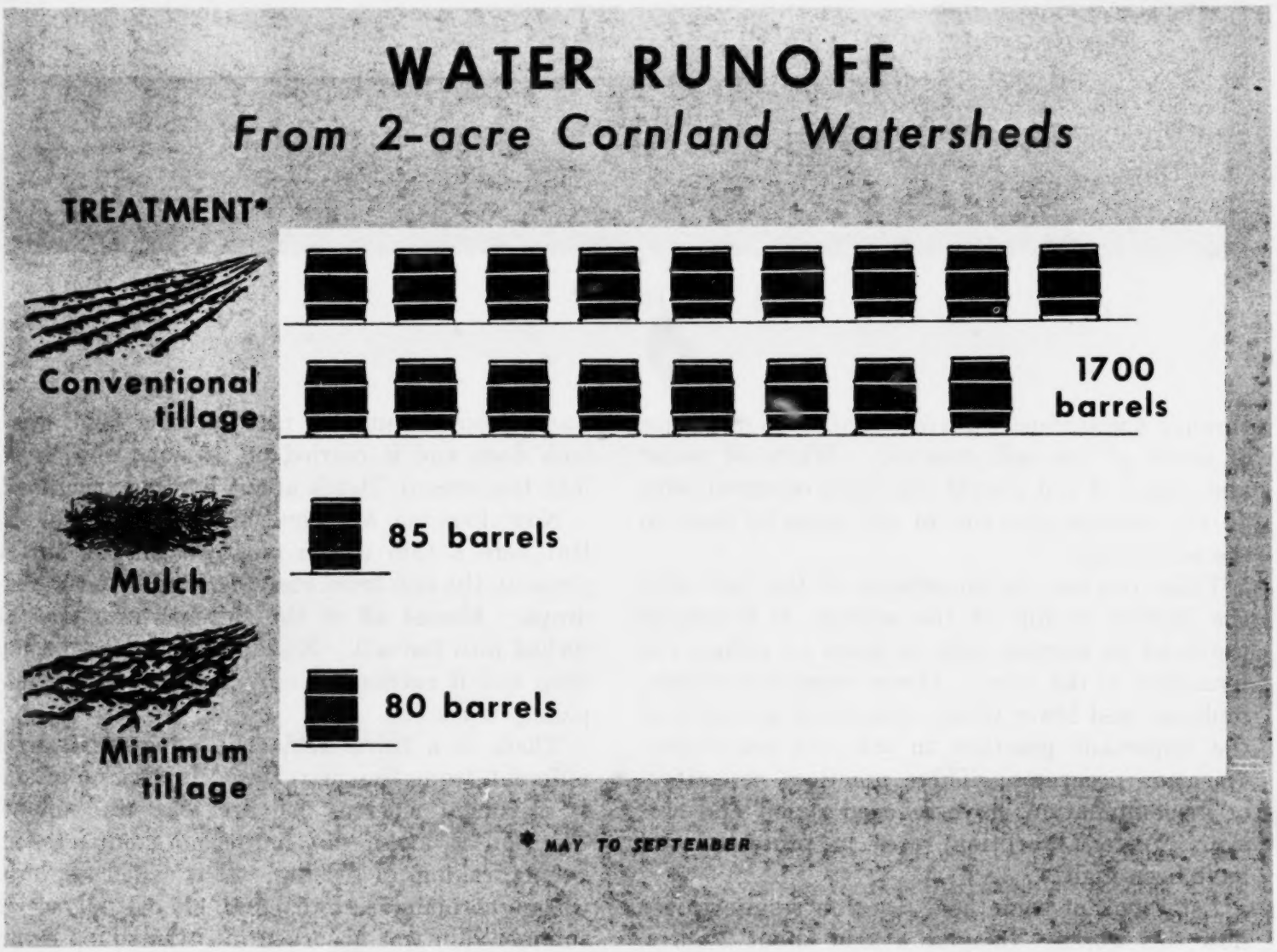

Figure 3.

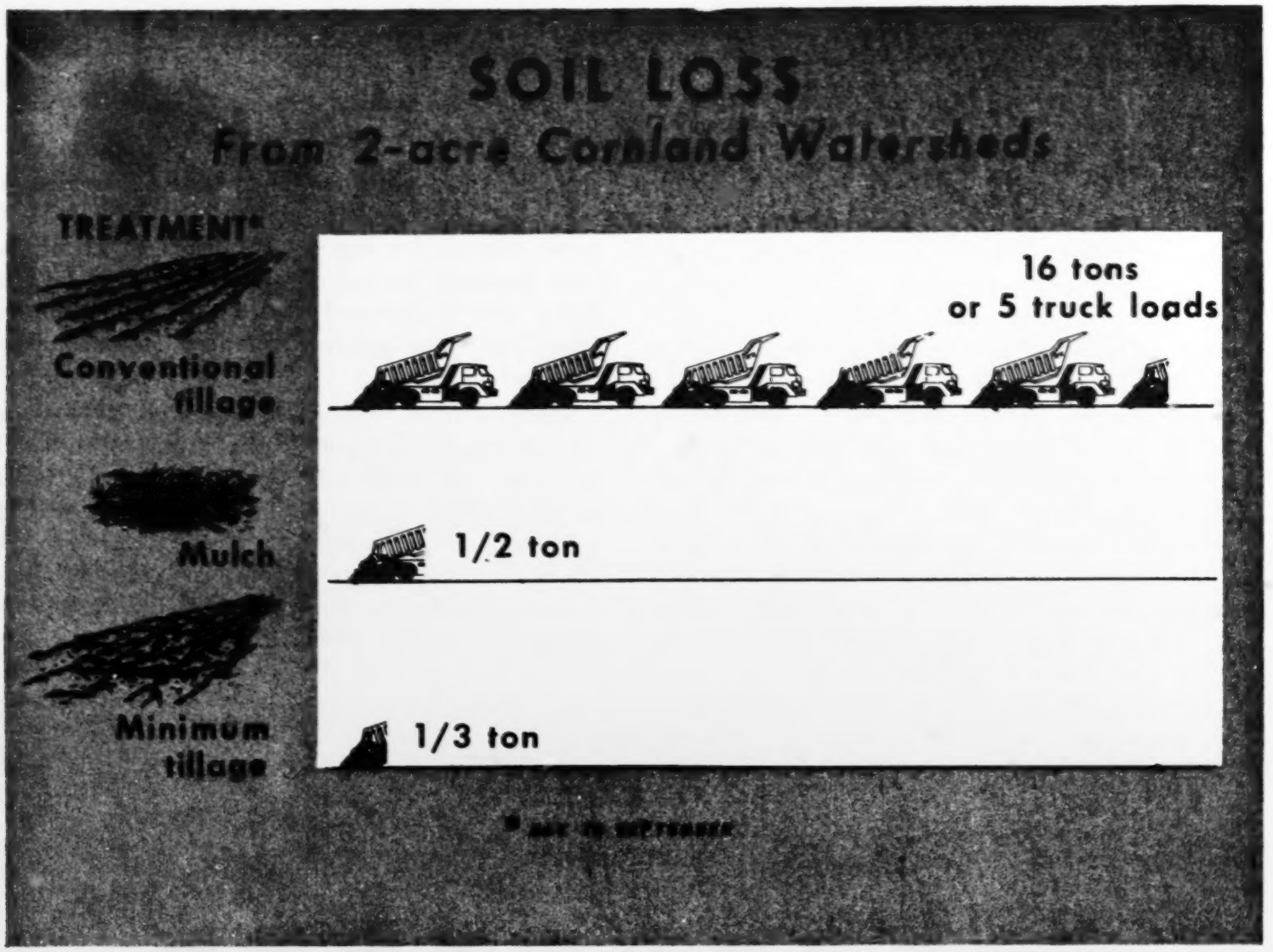

Figure 4.

through the surface crust fast enough to make use of much of this soil reservoir. Waste of water and waste of soil should not have occurred with all this storage reservoir of soil pores so close to the soil surface.

Thus, you see the importance of this test with the blotter on top of the sponge. It illustrates the need to manage soils in ways to reduce the formation of the crust. Dense vegetative covers, mulches, and fewer tillage operations are some of the important practices in soil and water conservation programs. These practices, separately or in combination, have reduced runoff and erosion. Water-absorption rates in protected soil have been high.

Let's look at some field research results to see how this works. Imagine a field about 2 acres, the size of half a city block. It is sloping. The corn rows on this field also slope. Runoff of water from a summer rain on this field was 1 inch deep and it carried off 16 tons of rich soil into the stream. This is about five big truckloads.

Now imagine a second field—the same size. But here a thin mulch of straw on the surface protects the soil from the splashing of large raindrops. Almost all of the summer rain was absorbed into the soil. Runoff water was 0.05 inch deep and it carried off only 1 ton of soil—just a pickup truck full.

There is a third field that appears strangely different from the first two. It has no mulch. It is rough, whereas the first one was smooth. The soil is loose, not hard and compacted by hoeing, raking, or disking. It is called minimum tillage cornland. Here, too, almost all of the summer rain was absorbed into the soil. Runoff water was 0.05 inch deep and it carried off only part of a pickup load of soil.

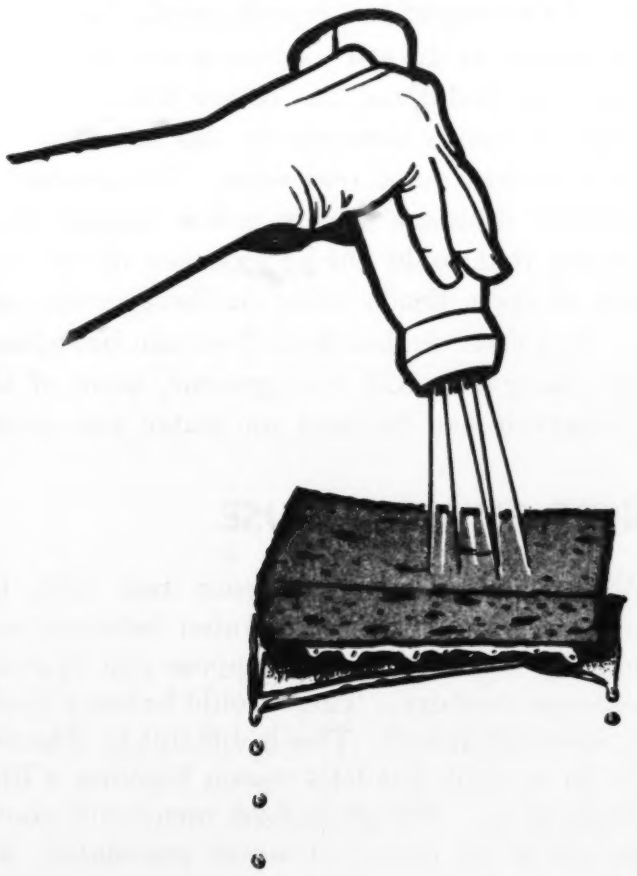

Figure 5.—Water being applied to a sponge placed over the blotter. This demonstrates what happens when rain falls on a porous topsoil over a firmly packed subsoil. The water runs off when it reaches the blotter.

Test No. 3: Blotter Paper Beneath Sponge

Now place the blotter paper on the bottom of the sponge (fig. 5). The sponge and blotter must be tilted slightly to allow for runoff, or "lateral seepage." After you start applying the water, note how long it takes for water to penetrate the sponge and seep out over the blotter. Note that there is no runoff over the sponge surface. Also note that no water is seeping through the blotter.

Consider, now, what you saw during this test. Of course, the water squeezed from the bottle represents a heavy rainstorm. The sponge is a highly stable, porous soil. The blotter paper represents an unstable, firmly packed soil. In some soils, the sponge corresponds to the topsoil with plenty of organic matter. Rainwater is absorbed and rapidly transmitted downward through this soil. The blotter suggests the presence of a subsoil through which water passes very slowly. When the upper surface of the subsoil has a slope like that shown by the blotter in this test, much of the water flowing over its surface seeps out of hillsides in springs and quickly contributes to stream flow.

The thickness of the soil sponge is an important item. It provides the *quickly available* volume for storm rainwater absorption. Because the big summer storms do not last long, there is usually only about an hour or two for water absorption. Water that cannot be absorbed in this short time often causes floods and serious erosion.

Sometimes the absorption volume of the sponge is exhausted during the period of the storm. The soil becomes saturated. Then we get runoff—even though there is plenty of unused water-absorptive capacity at lower depths, in and below the blotter. There is just not enough time during the storm for the absorbed waters to pass down into the pores of the blotter, which represents the fine-textured, less permeable subsoil.

To illustrate how soil erosion affects water absorption, under the conditions illustrated in figure 5, use a sponge half as thick. This thinner sponge represents a field with half the top soil lost by erosion. Now apply the water and see how much less quickly available absorptive space is provided. Also note how much sooner runoff over the blotter occurs—as compared with the thicker sponge.

Research results in Ohio showed that 3 inches of runoff came from an oatfield having a 6-inch depth of topsoil. From another oatfield having only a 3-inch topsoil depth, the runoff was twice as much. When erosion reduces the depth of topsoil, runoff increases. When runoff increases, the soil is eroded at higher rates. Thus the cycle accelerates. For the sake of water conservation alone, it is important to reduce soil erosion and retain as great a volume of quickly available water-absorption space in the soil as possible.

This test is not complete until we explore the possibilities of changing the water-transmission qualities of the blotter, or the subsoil. In figure 5, the blotter is very thin. The layer of slowly permeable material illustrated by the blotter may vary in thickness from only a few inches to several feet. If the soil layer is thin and if there is a soil

zone of higher permeability below it, then there might be some hope for puncturing the heavy material, thus providing for a greater volume of quickly available pore space for water absorption. This might be done mechanically or by plant roots.

Where the layer of slowly permeable soil is several feet thick, it is not practical to break completely through the layer by farm tillage equipment. Plant roots go into, but not through, this layer. Neither the mechanical nor the vegetative processes have yet been successful in noticeably improving the permeability of this thick, tight subsoil. Techniques of this type or new types may, in time, prove to be promising in extending the volume of quickly available pore space deeper into the soil. More research is needed.

Water for crop use in the humid region—east of the 100th meridian—comes mostly from rainfall absorbed by the soil. Much water for human, animal, and industrial use comes from the deep seepage of waters absorbed by the soil and from natural underground reservoirs. Floodwater on headwater drainage basins comes largely from rainwater that could not be absorbed by the soil. Many of these floods occur in the growing season. It is possible that flood flows can be reduced if, by changes in soil management, more of the soil reservoir can be used for water absorption.

WATER INTAKE AS INFLUENCED BY WATER USE

In the test with the sponge alone, as you continued to apply water, more seeped out from the bottom of the sponge. In nature, this process is called percolation. It is the major process of recharging ground-water supplies. No water seeped out until the sponge was soaked. Similarly, there is practically no recharge to ground-water supplies during the summer and fall when the soil has lost its wetness. It is not until the winter-spring season that the soil gets wet enough to allow deep percolation.

Ground-water supplies are an important source of water to all phases of our activity. The recharge processes must be recognized, protected, and improved (fig. 6). To illustrate how land use affects recharge, try to make water percolate from the sponge covered with blotter paper. It is a very slow process. Too much water flows off the surface, not enough soaks into the sponge. The same condition exists in fields of bare and compact soil.

From 39 inches of rainfall on a cornfield at a research station, 15 inches ran off; 24 inches soaked into the soil; and 3 inches percolated to the ground-water reservoir. On a grass field, only 1 inch ran off; 38 inches were absorbed; and 12 inches percolated to the ground-water reservoir. You can see that land use affected the intake of water and the amount of water in the soil for crop use and the amount reaching the ground-water reservoir for human use.

What would happen in your test with the sponge, if some water evaporated between each squeeze of the bottle? Or, suppose you squeezed the sponge very dry. There would be less percolation, wouldn't there? This is difficult to illustrate with the sponge, but let's reason together a little on the subject. The grass field, mentioned above, from which 12 inches of water percolated, was shallow-rooted grass. The vegetation used all the available water from only a foot or two of the soil; then it stopped using water. It could not get water from greater soil depths. The soil below this depth remained wet. Fall and winter rainfall merely had to wet a shallow soil depth before deep percolation occurred. This is like starting your test with a fairly wet sponge or never squeezing it quite dry.

At this research station, there was another field. This one was in alfalfa and bromegrass. Roots penetrated deep into the soil. This vegetation continued to use water long after the shallow-rooted grass in the other field had stopped using water. It was like starting your test with a very dry sponge. Then when the fall-winter rains came, it took a long time before the entire soil depth was wet enough to allow percolation. In fact, only 6 inches of percolation occurred.

Now you see there are other ways of changing the amount of recharge to ground water. Of course, it must be realized that there are some conditions in which there will be no sizable effect.

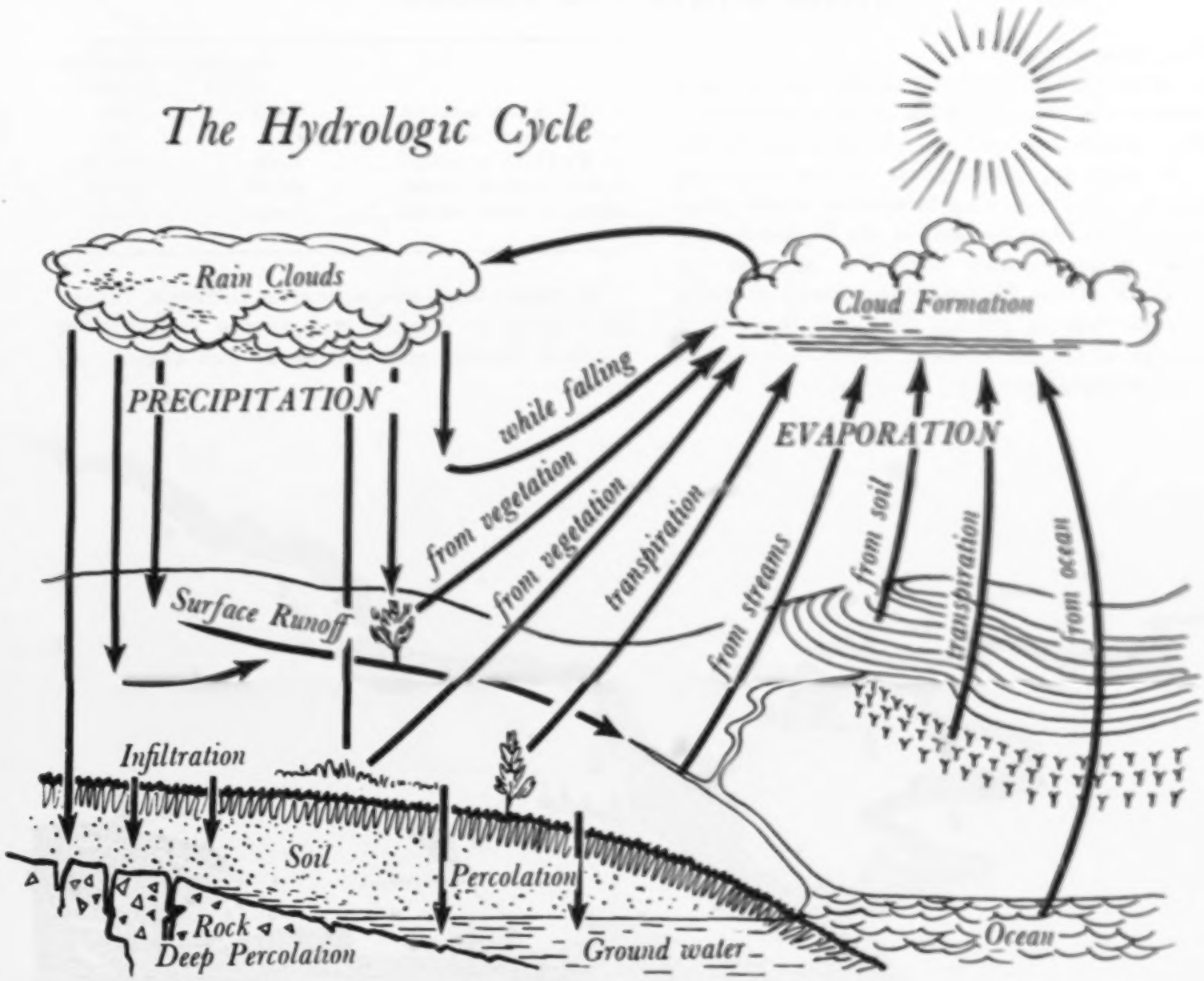

Figure 6.—The hydrologic cycle. Water travels from ocean to sky to land and finally back to the ocean.

It may be that some soils are so shallow that rooting depth of various kinds of vegetation may not differ noticeably. Furthermore, rains may come so often that the soil never quite dries out. Then there would not likely be any sizable change in percolation. Also, there are some sections of the country having less than 25 inches of rainfall where there is not enough water for deep percolation regardless of the land treatment.

In the above example, where we had the deep-rooted vegetation, more crop was produced. More water was used by the vegetation. There was less available in the ground-water reservoir for human use. Studies are being made at several research stations to improve the efficiency of water use by crops and to evaluate such effect on water supplies for other needs.

WATER INTAKE AND FLOODS

What causes floods?

To get at the root of the flood problem, we have to consider the characteristics of water delivery—in other words, how nature delivers water to the soil. It helps to catalog these factors according to season. The following tabulation shows what they are for the humid areas of the United States.

These characteristics may be different for other areas of the United States—arid or semi-arid areas—but in general they are basic to a knowledge of the cause of floods and soil erosion and to developing remedial measures.

	Dormant season	*Growing season*
FORM of precipitation	Snow or rain	Rain.
RATE of rainfall	Low	High.
DURATION of rainfall	Long	Short.
DROP SIZE of rainfall	Small	Large.
AREA of storm rainfall	Large	Small.

To relate these characteristics to floods, it may be helpful to classify and discuss two distinct kinds of floods—*upstream floods* and *downstream floods*.

Figure 7.—Upstream floods generally cover small areas and occur during the growing season.

Upstream Floods

Upstream floods are prominent in regions like the Ohio River basin on watersheds having drainage areas up to about 500 square miles. They occur during the growing season when the soil is not normally saturated. The area the flood covers is generally small—as little as 1 square mile (fig. 7). To understand why this is true, look at the tabulation on page 8. Under the heading, "Growing season," note that the *area* of storm rainfall is small; the *duration* is short; and the *rate* of rainfall is high. This means that, although the flood on a 1-square-mile watershed may be severe, the flow in adjacent streams may be only a trickle. When the floodwater from one stream combines with the trickle flow of its neighboring areas, there is usually no flood problem in the larger channel.

One way to reduce the flood flow from such a situation would be to take steps to allow the soil to absorb more water. The result, naturally, would be less runoff. Some of these practices are: reforestation, contour tillage, residue management, improved cropping systems. All of these practices are extremely helpful. Unfortunately, we are not able to open the pores in heavy soils (the blotter beneath the sponge) and to keep them open to the extent of reducing runoff from the big storm. Therefore, we build detention reservoirs to hold the excess surface water temporarily.

Floodwater detention reservoirs are usually designed and operated to reduce flooding in specific tributaries of a river basin. Some are automatic, in that they have fixed openings to provide controlled flow. Some are manually controlled. Almost all operate in such a way that stored floodwater is released as rapidly as possible to develop storage capacity for the next storm.

Sometimes, water released from detention reservoirs is only a small part of the total flow in downstream channels. Thus, we see that a reservoir or a system of reservoirs designed to prevent flooding in a particular area cannot be expected to prevent flooding throughout the entire river channel downstream.

Downstream Floods

Downstream floods—those that cover a wide area and make the newspaper headlines—are more prominent in the winter-spring season. Rainfall rates at that time are usually low, and there is no problem of absorbing the low-intensity rainwater at the start of the storm. But these dormant season storms last a long time and they cover large areas. The soil becomes quite wet; its capacity to absorb more water becomes insignificant. As a result, runoff occurs. The rate of runoff, however, is small because the rainfall rate is low. Normally, there is no flood problem on small areas at this time. However, when thousands of small areas contribute their combined flow to the large basin channel, or river, a major flood occurs (fig. 8). On Ohio River basin watersheds of 1,000 square miles or more, about 75 percent of the greatest annual floods occur in the dormant season. Sometimes melting snow adds to large river floods.

A study of the sponge-blotter demonstration enables us to reason through this kind of flood problem and arrive at some idea of the way to remedy it.

Long-duration rainfall of the dormant season thoroughly wets the soil sponge. Runoff occurs mainly because the soil intake capacity is exhausted, or because the soil may be frozen. One cannot expect land treatments alone to prevent such floods. Of course, erosion control programs on the land are beneficial because they reduce sedimentation in reservoirs and channels. To prevent or reduce these floods, more water must be stored on the surface or confined to river channels by better levee systems or by channel improvement works.

It is important to remember that headwater flood prevention structures do not eliminate the need for downstream reservoirs and river channel and levee improvements. Likewise, downstream reservoirs do not prevent flood damage in the headwater areas. Because upstream floods do not receive much national publicity, one may think that they do not cause much damage. Collectively, however, the damage from them is about as great as that caused by the downstream floods.

Figure 8.—Downstream floods cover wide areas and occur during the dormant season.

THE ROLE OF RESEARCH

As the sponge demonstration indicated, a porous, well-managed soil can do much to reduce summer flooding—so common to small upland watersheds. Fortunately, Nature offers an opportunity for man to do something about improving water intake. Research studies show that the capacity of soil to absorb moisture generally increases during the growing season, because the soil is drying out. At times, a 40-inch depth of soil is capable of absorbing as much as 10 inches of water IF conditions are favorable.

This "if" and others provide some of the incentive in land and water management research. Consequently, soil scientists, engineers, and hydrologists are studying ways to use and treat the land to improve the rates and amounts of storm water absorption during the growing season. Their goals are to reduce floodwater runoff and to increase the amount of storm rainfall available for human and crop use.

No matter where the problem lies—in water use, water management, or flood prevention—the subject of *water intake by soil* is an important one that deserves much study.

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